Predicting The Risk of Stenting using Finite Element Modeling

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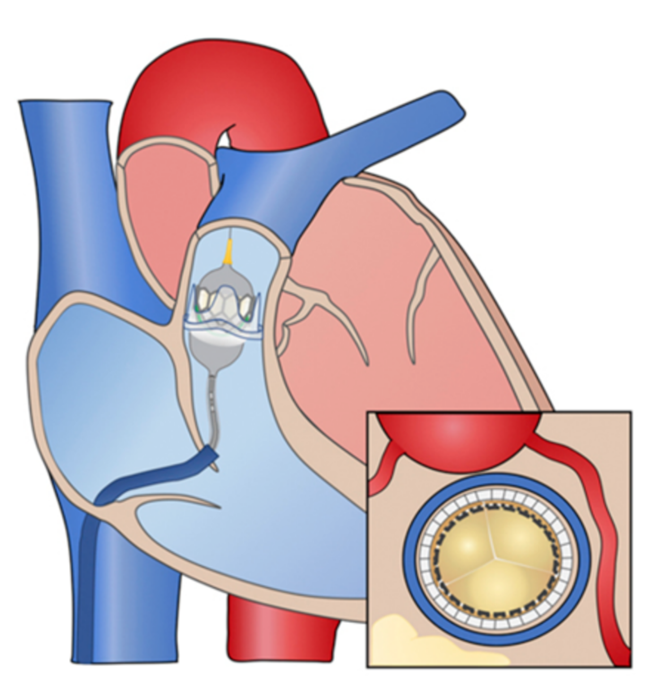
Background

Transcatheter Pulmonary Valve Implantation (TPVI) is a way of treating patients with outflow dysfunction due to congenital heart disease. One major benefit is that it is much less invasive than open heart surgery because it is done using a catheter all internally. It is hard to predict the different risks associated with it like distortion of the aorta or coronary arteries because this cannot only be done from imaging which is currently what is accessible.

Prior Knowledge

There are very few studies like ours going on. There was one with three patients that was done in 2018 that reported long computational times.[1] Our method is a faster and more practical way to analyze TPVI cases that gives accurate results. Another study discusses the future of TPVI and how advancements are being made to create smaller and more compliable stents.[2] With our method, we could adjust the program to account for these differences and still provide reliable information for the doctors.



Caughron, H., et al., 3rd, Book, W. M., McConnell, M., Block, P. C., & Babaliaros, V. (2018). Repeat Pulmonary Valve Replacement: Similar Intermediate-Term Outcomes With Surgical and Transcatheter Procedures. *JACC. Cardiovascular interventions*, *11*(24), 2495–2503. https://doi.org/10.1016/j.jcin.2018.07.042

Figure 1
Transcatheter Pulmonary Valve Implantation (TPVI) Diagram

Goals for this Research

1. Create models that are consistent with the clinical outcomes
2. Gain a better understanding of the adverse effects of TPVI and prevent unnecessary procedures.

Methods

The first step to this project was obtaining the CT scans from the physician. From there, we could upload the scans to a program called Seg3D where I would go through each slide of the CT and trace the aorta, pulmonary artery and the coronary arteries. The segmented CT scans are then used to create a 3D model. From here a custom Matlab code is used to determine the correct stent placement. Then, the expansion of the stent is simulated in an application called FEBio using finite elements analysis. During this time displacement, strain, stress and changes to the lumen are calculated. This provides us and the doctor the information we need to determine the risk of the patient experiencing aortic or coronary artery compression.

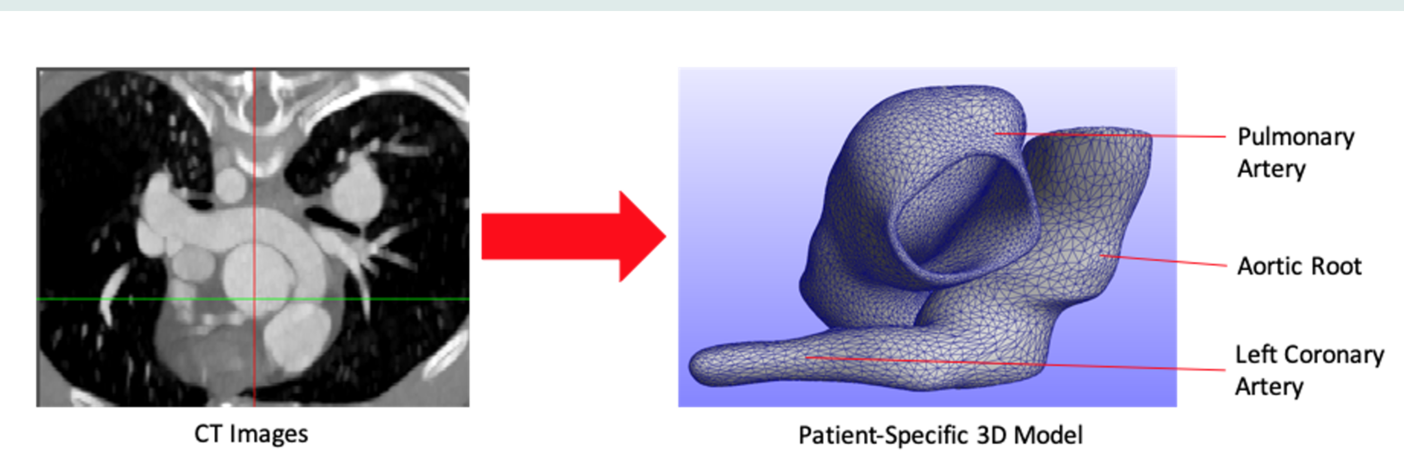


FIgure 2
Going from a CT scan to a 3D Model

The Resulting Model

This is an example of the final output from our framework. The color change towards the middle of the aorta represents the displacement, stress, strain and change in lumen shape and area that results when the stent is placed in pulmonary artery. For this patient the maximum displacement is 6.23 mm and the volume loss is 85.52 mm^3. The displacement seen is considered mild and the model correctly predicted what happened in the clinic. This is one of about 8 models we are working on and aligns with the clinical outcome which is that there is no issue placing the stent in this patient.

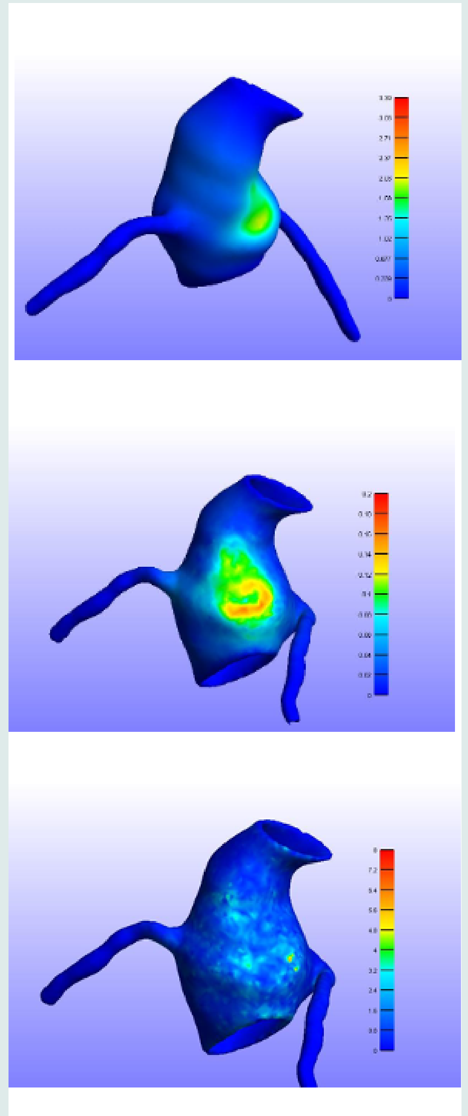


Figure 3
The aorta and the coronary arteries with strain from stent shown, the more severe the strain the warmer the color

Future Implications

Our work on this project will continue as we get more CT scans and improve our Matlab code. Since every patients vascular anatomy is unique, it is hard to make one blanket code that handles them all.

The overall goal of this project is to create accurate clinical outcomes for the catheter lab physicians. This is so they do not perform expensive and unnecessary procedures on TPVI patients. We have correctly predicted the cases we've seen so far and hope to continue to help.

Sources

1 Caimi, Alessandro, et al. “Prediction of Stenting Related Adverse Events through Patient-Specific Finite Element Modelling.” Journal of Biomechanics, vol. 79, 2018, pp. 135–146., doi:10.1016/j.jbiomech.2018.08.006.

2 Law MA, Chatterjee A. Transcatheter pulmonic valve implantation: Techniques, current roles, and future implications. World J Cardiol. 2021 May 26;13(5):117-129. doi: 10.4330/wjc.v13.i5.117. PMID: 34131475; PMCID: PMC8173335.